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HIGH FREQUENCY MODULATED AND TIME RESOLVED PHOTOLUMINESCENCE: TOWARDS A FULL TEMPORAL CHARACTERIZATION ON III-V SEMI-CONDUCTOR MATERIALS INCLUDING SLOW MECHANISMS

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ABSTRACT: Time resolved Photoluminescence is a standard technique to probe the recombination paths in photovoltaic semiconductors. However, the effect of slow mechanisms as de-trapping often appears at the end of the decays, and are sometimes covered by the noise. Furthermore, in complex decay cases, one has to postulate recombination mechanisms and to perform simulations, without insurance that the fitting procedure will lead to unique fits. In this context we upgraded our Frequency Domain setup, also known as High Frequency Modulated Photoluminescence up to 100 MHz. We coupled the both kind of measurements, TRPL and HF-MPL with drift diffusion simulation including light reabsorption. Finally, we present several kind of III-V material responses and show how the response can be interpreted more reliably using the 2 methods and the simulations.

Keywords: Photoluminescence, III-V semiconductors, Defects

1 INTRODUCTION

Time Resolved Photoluminescence (TRPL) is considered as a standard technique to measure carrier lifetime in thin film semi-conductors down to sub ns time scale. Nevertheless, the interpretation of the TRPL temporal decays is not trivial when presenting non mono-exponential behavior – and even for mono exponential decay- as it can involve recombination, extraction and trapping mechanisms. Another approach based on Modulated Photoluminescence (MPL) has been developed previously for silicon materials [1] and consists in the measurement of the phase shift between the PL signal and the modulated illumination source. It is used to deduce carrier lifetime from the PL time delay. This technique has also been demonstrated on III -V materials up to 100 MHz [2-3].

We upgraded our MPL setup by extending the modulation frequency range up to 100 MHz using a Time Correlated Single Photon Counting (TCSPC) device, which is the state of art HF-MPL setup to our knowledge and suitable for probing direct gap materials, aiming to provide complementary information for TRPL measurement. High Frequency (HF)-MPL can operate at specific excitation conditions and enable to investigate slow mechanisms such as carrier trapping [4] as well as faster decays. Novel time dependent simulation models based on drift diffusion equations were built to discriminate different recombination mechanisms and to extract carrier lifetime, surface recombination velocity and relevant trapping parameters from both HF-MPL and TRPL experiment data [5].

Finally, we applied this method combining the two types of experiments associated with numerical simulation in order to probe several III-V materials such as InP and GaAs. The present work presents the possibilities of such an approach.

2 METHODS

2.1 Experimental

The light sources are a 638 nm wavelength intensity modulated laser and a 532 nm pulsed laser with 10 ps pulse duration (full width at half maximum) at 1 MHz repetition rate. The modulation is based on sinusoidal variations of the light intensity around a given working point, with modulation ratio of roughly 60%. The beam size was measured to be 130 μm on the sample. The photoluminescence signal (PL) is then collected. To detect the signal with an optimal sensitivity we used a Single Photon Avalanche Detector and a Time Correlated Single Photon Counter (TCSPC) for both kind of experiments. The LabVIEW software allow for reconstructing one decay in TRPL mode or one period of the modulated signal. In such configuration we obtain a unique experimental setup that allows to record fast modulated signal with a high detection sensitivity. In classical modulated experiments when one uses a fast detector, the sensitivity is often strongly degraded (compromise between speed and gain). Once the modulated signal is recorded, we can extract the phase and amplitude of the first harmonic by fast Fourier transform.

2.2 Simulation

The simulations take into account the common one dimensional drift diffusion equation, and include if necessary SRH recombination centers in the bulk or at the surface. The optical model includes Beer Lambert absorption for the entrance and use the generalized Planck law for the output calculation. Indeed, the full reabsorption is calculated (excluding recycling) which can change strongly the curvature of the decays and the associated extracted parameters.

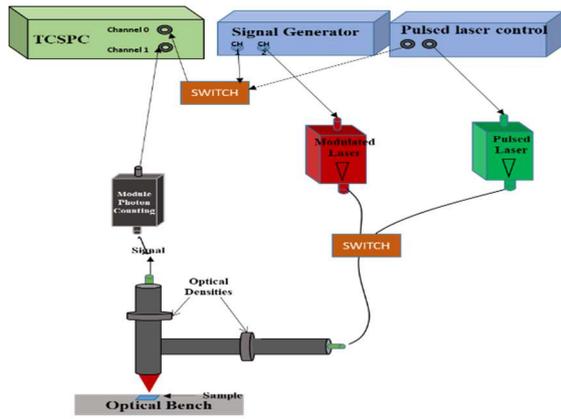


Figure 1: Scheme of the setup.

3 RESULTS AND DISCUSSION

3.1 Validating the setup with Highly Doped InP ($8 \times 10^{18} \text{ cm}^{-3}$)

In this section we perform the following procedure: we record a TRPL set of decays at several illumination fluxes, followed by HF-MPL spectra also at several illumination fluxes at the same point of the sample presented in figure 2.

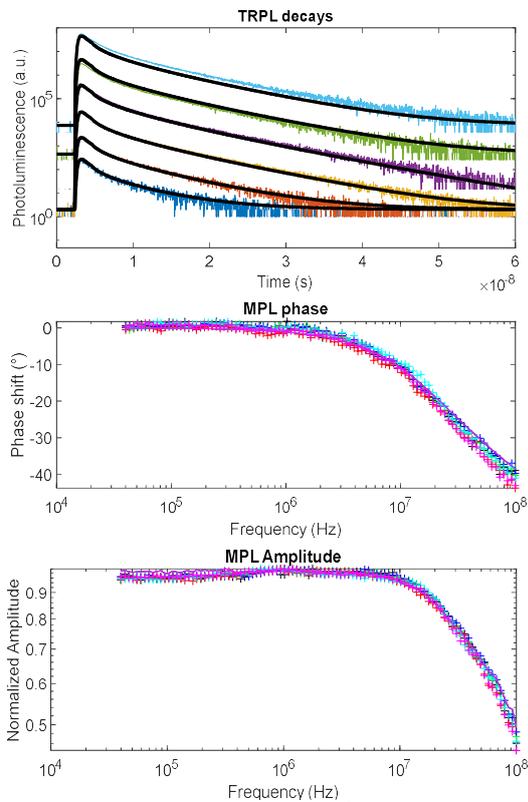


Figure 2. TRPL decays at flux 2×10^6 photons/pulse/cm² times 1, 10, 100, 1500, 2×10^4 , 2×10^5 . Black lines are the fits from drift diffusion solver. MPL phase and amplitudes at 4×10^{15} photons/cm²/s times 1 (black), 10 (green), 100 (blue), 1000 (red), 10^4 (cyan) 10^5 (magenta). Crosses represent experimental data, solid lines simulations.

Then, with respects to the heavy doping, we can fit the TRPL data with a single minority carrier lifetime (8.2ns) and a surface recombination velocity (2.5×10^5 cm/s). Please note that we don't normalize our TRPL data, keeping the natural spacing between each TRPL curve. For the highest injection, calibrated neutral densities are used. Finally, we use these extracted values to simulate the MPL and the phase and amplitude of the data match nicely the experimental ones. This excellent match demonstrates our setup accuracy.

3.2 Interpreting phase splitting in the MPL spectra by the presence of surface trapping on InP.

Another study on Highly doped n-type InP ($3.5 \times 10^{18} \text{ cm}^{-3}$) revealed an extraordinary long decay associated with MPL split of the phase and amplitude with respects to injection (figure 3).

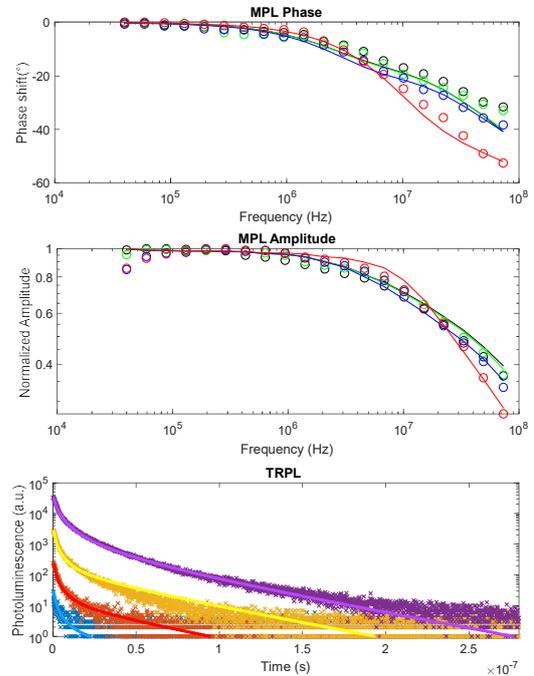


Figure 3. MPL phase and amplitudes at 10^{17} photons/cm²/s times 1 (black), 10 (green), 100 (blue), 1000 (red), Circles represent experimental data, solids lines simulations. TRPL decays at flux 8×10^8 photons/pulse/cm² times 1, 10, 160, 1600. Crosses represents the data, solid lines are the fits from drift diffusion solver.

Please note the fit was performed on all the TRPL and MPL data simultaneously. In this case, several set of parameters was found for either TRPL or HF-MPL but was found a unique set for common data fitting. It claims for the presence of a surface DOS situated at 0.3 eV above the valence band.

A detailed study of several samples issued from the same wafer with different surfaces treatments will be published soon [6], studying the influence of surface traps on the phase splitting and presenting in details the technics.

3.3 Performing measurements on GaAs diodes

The experiment was also conducted on GaAs solar

cells and data are plotted on figure 4. The TRPL decays are too short to extract any information since the carriers are rapidly separated by the junction field. However, the light bias of the MPL allows for observing a response. The phase shift exhibits V-shapes similarly to [4]. In this previous article, the V-shape was found to be a consequence of a trap center close to on band in the bulk of the absorber. However, the V shape was appearing at low injection when it appears here at high injection. The reason for this difference of behavior is probably due to the presence of the junction and the charge separation. If the trap center is situated inside the junction, it will be necessary to reach a high injection level to screen the electric field. Once the electric field screened, we will start to get PL from this region, leading to the appearance of the V-shape Further simulation is under work to find the position of the probable defect creating this pattern.

4 CONCLUSION

A novel characterization tool combining TRPL, HF-MPL and drift diffusion simulation has been presented and validated. It allows for probing complex recombination mechanisms where the TRPL alone is not sufficient. The tool has been validated on several InP wafers and is under work for probing III-V solar cells junctions. It will be applied in the future to full devices

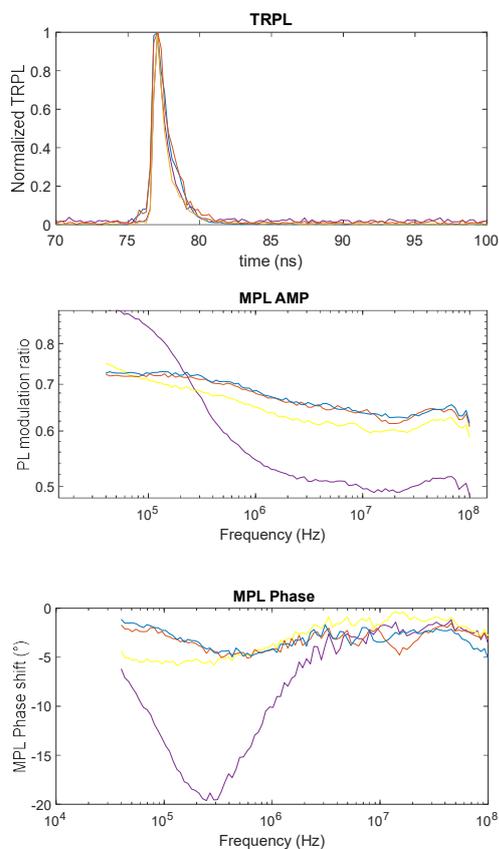


Figure 4. GaAs solar cell: Normalized TRPL at 4×10^8 photons/pulse/cm² times 1 (blue), 10 (red), 200 (yellow), 2000 (purple). MPL amplitude and phase

10^{18} photons/cm²/s times 3 (blue), 10 (red), 30 (yellow), 100 (purple).

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REFERENCES

- [1] R. Brüggemann and S. Reynolds, "Modulated photoluminescence studies for lifetime determination in amorphous-silicon passivated crystalline-silicon wafers," *J. Non-Cryst. Solids*, vol. 352, no. 9–20, pp. 1888–1891, Jun. 2006, doi: 10.1016/j.jnoncrsol.2005.11.092.
- [2] P. Vitta, "Luminescence study of ZnSe based scintillators in frequency domain," *Lith. J. Phys.*, vol. 48, no. 3, pp. 243–247, 2008, doi: 10.3952/lithjphys.48312.
- [3] S. Miasojedovas, P. Vitta, I. Reklaitis, R. Kudz, and I. Pietzonka, "Photoluminescence Decay Dynamics in Blue and Green InGaN LED Structures Revealed by the Frequency-Domain Technique," vol. 45, no. 7, pp. 3290–3299, 2016, doi: 10.1007/s11664-016-4557-7.
- [4] B. Bérengruier *et al.*, "Defects characterization in thin films photovoltaics materials by correlated high-frequency modulated and time resolved photoluminescence: An application to Cu(In,Ga)Se₂," *Thin Solid Films*, Nov. 2018, doi: 10.1016/j.tsf.2018.11.030.
- [5] B. Berenguier, N. Moron, W. Zhao, J. F. Guillemoles, J.-P. Kleider, and L. Lombez, "High-Frequency Modulated Photoluminescence: a simulation study of cases describing the signature of carrier recombination and trap centers," in *IEEE 46th Photovoltaic Specialists Conference (PVSC)*, Chicago, IL, USA, 2019, p. 352-358.
- [6] Wei Zhao, Cendra Rakotoarimanana, Anne Marie Goncalves, Arnaud Etcheberry, Mathieu Frégnaux, Laurent Lombez, Baptiste Bérengruier and Jean-François Guillemoles (3), "Surface recombination mechanism in InP with and without phosphazene monolayer probed by combined time-resolved photoluminescence and high frequency-domain photoluminescence technique", to be submitted...